ERDC/CHL TR-15-12

Coastal and Hydraulics Laboratory

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Numerical Sedimentation Study of Shoaling on the Ohio River near Mound City, Illinois

David Abraham, PhD., P.E., Nate Clifton, and Barry Vessels

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Final report

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Prepared for U.S. Army Corps of Engineers
Louisville District

Abstract

A numerical sedimentation study was conducted on the Ohio River in the vicinity of Mound City, IL. The purpose of the study was to evaluate shoaling tendencies between River Miles 971 and 973.2. The model was used to determine if raising the elevations of two existing transverse structures would reduce shoaling at that location. First, the model was run in a base (as is) condition and calibrated to both hydraulic and sediment field measurements. Then the crest elevations of the existing dikes were raised by one foot (ft). Plan condition simulations were then made for a steady-state bank-full flow of 498,650 cubic feet per second (cfs) (14,120.4 cubic meters per second (cms)) and an unsteady simulation consisting of a 48-day hydrograph from 14 Jul–31 Aug 2012, which had a peak flow of 152,000 cfs (4,304.2 cms) . The steady-state simulation showed a difference of 0.16 ft (0.05 m) between the base and plan conditions and for the unsteady simulation, a difference of 0.33 ft (0.1 m). These results indicate that raising the structures 1 ft has little effect on shoaling in the navigation channel. In the future, this model can be modified to test additional structural and/or operational changes that might reduce shoaling.

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Preface

This study was conducted for the U.S. Army Corps of Engineers, Louisville District. The technical monitor was Barry Vessels.

The work was performed by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), during the time period of March 2013 to May 2014. The principal investigators were David Abraham and Nate Clifton. At the time of publication, Jim Lewis was Acting Chief of the River Engineering Branch; Ty Wamsley was Chief of the Flood and Storm Protection Division; and José Sánchez was CHL Director. LTC John T. Tucker III was the Commander of the ERDC, and Dr. Jeffery Holland was the Director.

ACKNOWLEDGMENT: This study was funded by the Louisville District, U.S. Army Corps of Engineers.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet per second	.028317	cubic meters per second
feet	0.3048	meters
tons (2,000 pounds, mass)	907.1847	kilograms
inch	.0254	meters
tons [U.S., 2,000 pounds, mass, (short)]	1.1023	metric tons
mile	1.609	kilometers

1 Introduction

1.1 Purpose

This report describes a sedimentation study on the Ohio River in the vicinity of Mound City, IL. The study was conducted by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). The purpose of the study was to assist the U.S. Army Engineer District, Louisville, with the evaluation of shoaling tendencies in the Ohio River navigation channel between River Miles (RM) 971 and 973.2. The evaluation required numerical sedimentation modeling with the objective being to determine if raising the crest elevations of two existing river-training dikes could help reduce the adverse sedimentation tendencies.

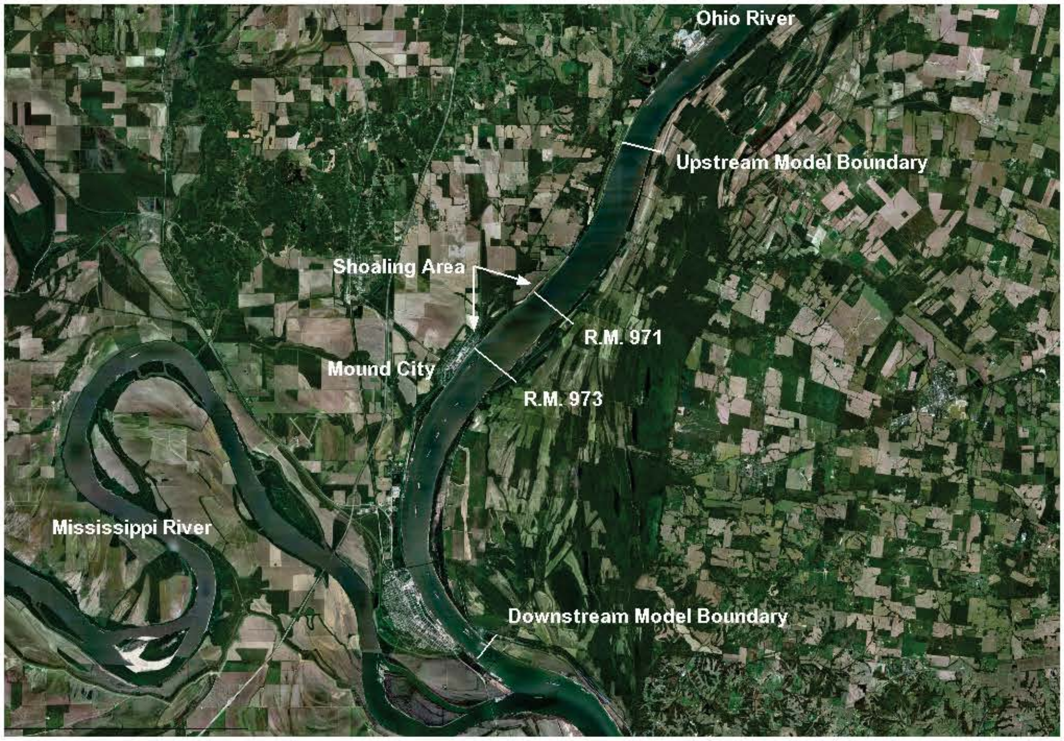
1.2 Background

District personnel noted that during low flows, increased sedimentation occurs in the navigation channel between RM 971 and 973.2. A suspected reason for this is the increased conveyance in the side channel when the training dikes are overtopped. If this is in fact the most important contributor to the shoaling, then raising the dike elevations could be helpful in increasing main channel conveyance and thus reducing local sediment deposition.

1.3 Site description

Figure 1 shows the confluence of the Mississippi and Ohio Rivers, the upstream (RM 967) and downstream (RM 980) boundaries of the model domain, and the main area of interest for this study, which is the navigation channel between RM 971 to 973.2. The downstream boundary is just south of the USACE Cairo Gage OH111 on the Ohio River at Cairo, IL.

Figure 1. Site map showing model boundaries and shoaling area.

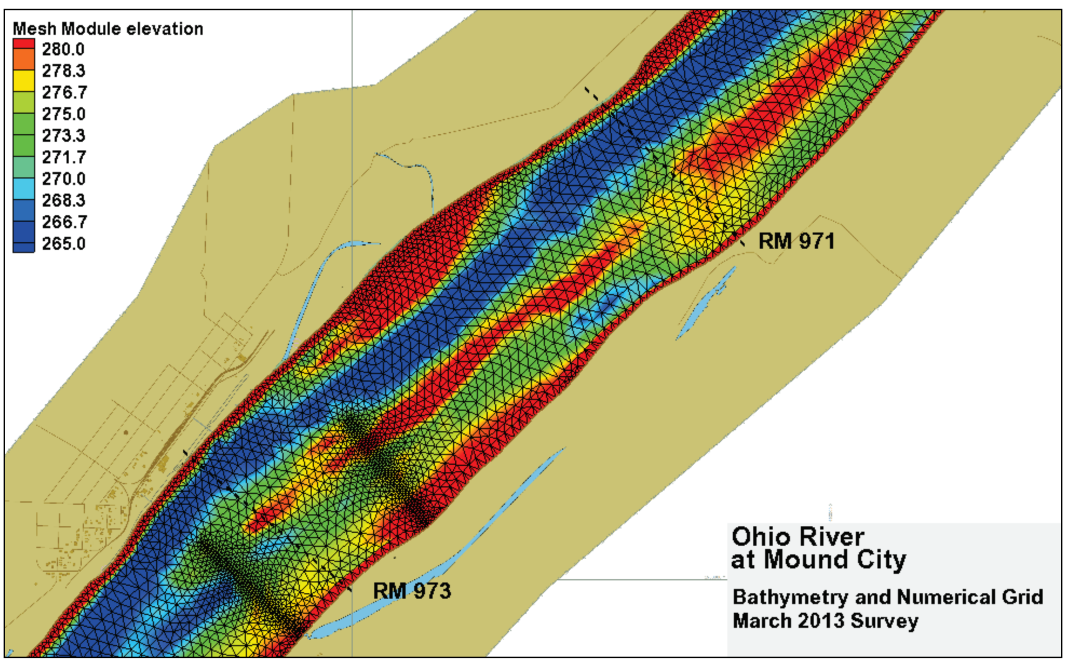


2 Methodology

2.1 Numerical model preparation

A numerical simulation of flow and sediment transport was conducted for the Ohio River in the vicinity of Mound City, IL. The numerical model used was the two-dimensional (2D) sediment transport version of the Adaptive Hydraulics (AdH) code with sediment transport libraries developed at ERDC-CHL. In order to address whether or not raising the elevation of the two dikes in the study area would affect shoaling patterns in the navigation channel, two numerical simulations were necessary. The first represented the bathymetry of the river at the time of field data collection. Figure 2 shows a portion of the study area numerical grid along with colored contours of bathymetric elevations. This grid uses bathymetry data from the ERDC-CHL data collection effort conducted during the week of 25 March 2013. Flow is from top right to bottom left. The two structures are upstream and downstream of RM 973, indicated by the higher resolution grid cells.

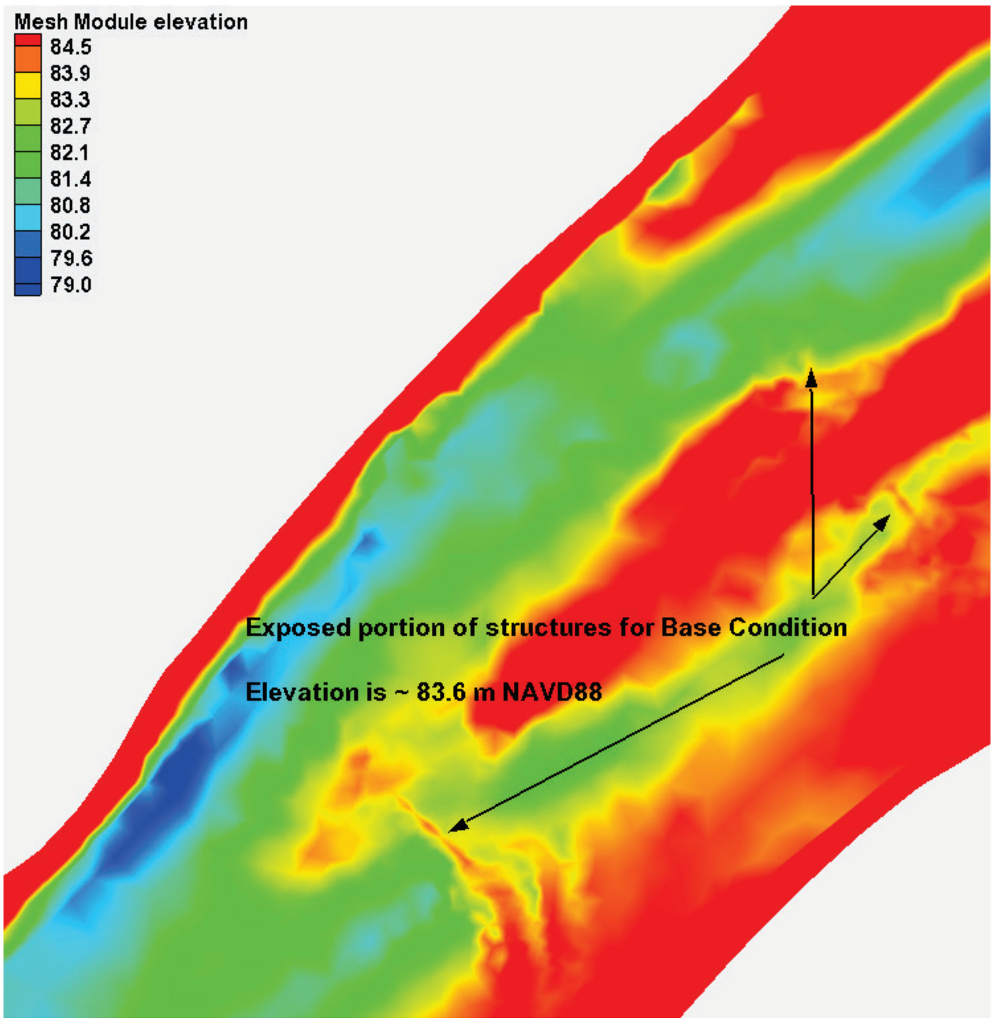
Figure 2. A portion of the numerical grid showing the two structures.



The navigation channel is apparent as the dark-blue band running from the top right to the bottom left of the figure. The two structures were placed in the river in the early 1900s and have since been partially covered with sand. Figure 3 shows that significant portions of the upstream structure are now

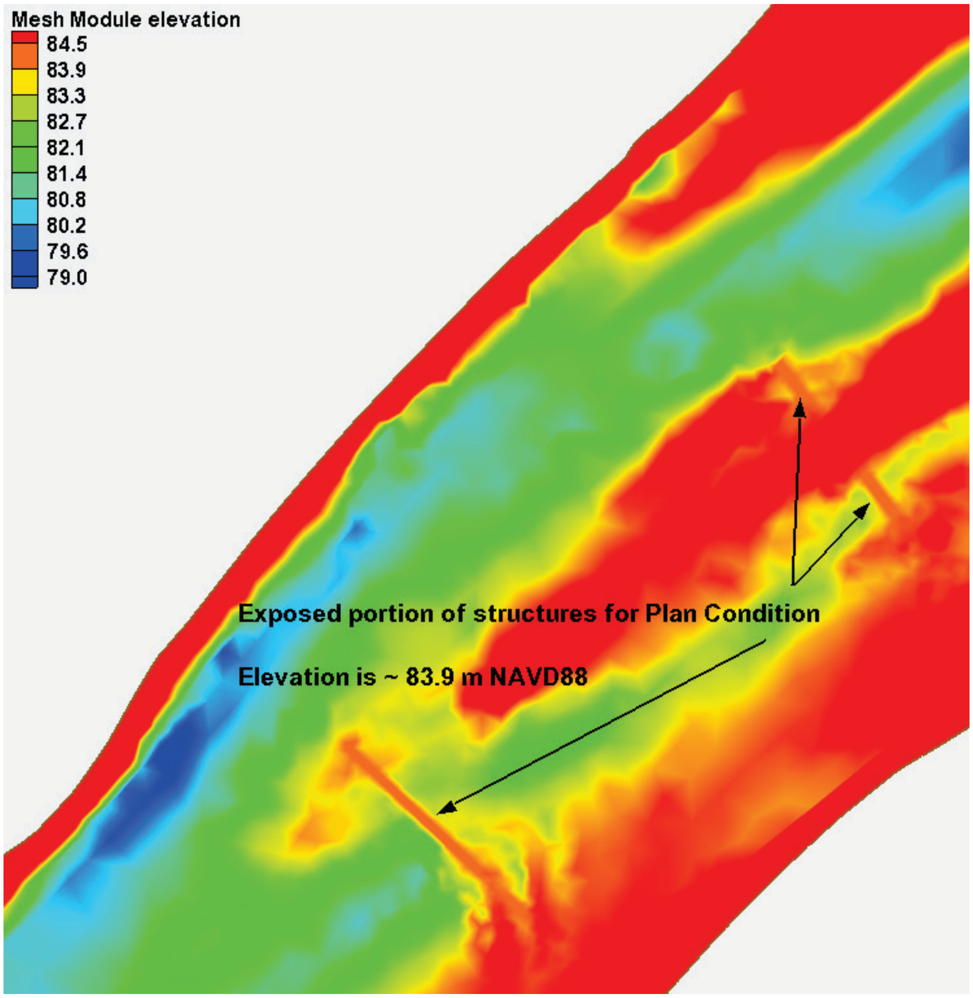
covered by a large sand bar and the downstream structure by large dunes. However, the alignment and extent of the exposed crests are still visible and are shown as the yellowish-red linear features noted in the figure. The present crest elevation of the exposed portions of the rock structures, obtained from the March 2013 multibeam surveys, is approximately 274.2 feet (ft) (83.6 m (meters)) NAVD88.

Figure 3. Exposed portion of structures with crest elevation as noted.



In the plan-condition simulation, any point of the sand bar or dune that was along the longitudinal axis of the dike and was below 275.2 ft was raised to 275.2 ft. All parts of the sand bar or dunes that were higher than 275.2 ft were left at the higher elevation. The raised structures are shown in Figure 4.

Figure 4. Raised structures for the plan condition.

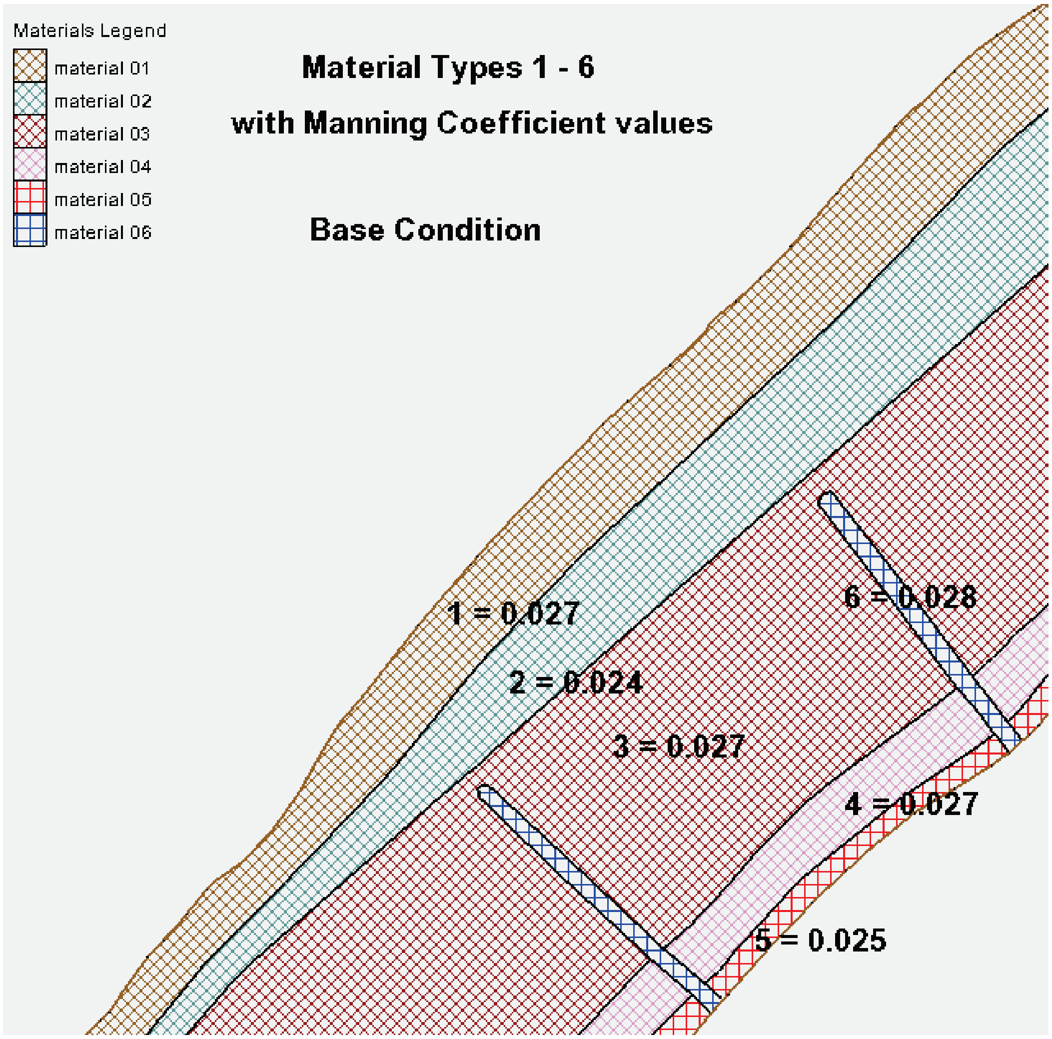


2.2 Model validation: Hydraulics

A flow of 498,650 cubic feet per second (cfs) (14,120.4 cubic meters per second (cms)) was the average flow during the 27 March 2013 field data collection time period. The downstream boundary elevation of 308.56 ft (94.05 m) NAVD88 came from Memphis District USACE Cairo Gage OH111. These were the boundary conditions used for a base-condition, steady-state (one continuous flow) simulation used to validate the model.

The Manning coefficients used in the base-condition simulation for the various model material types are shown in Figure 5. Since the variation of the river bottom composition varied mainly laterally and not much longitudinally, the five different types generally run the length of the model. The exception to this is the type 6 for the structures.

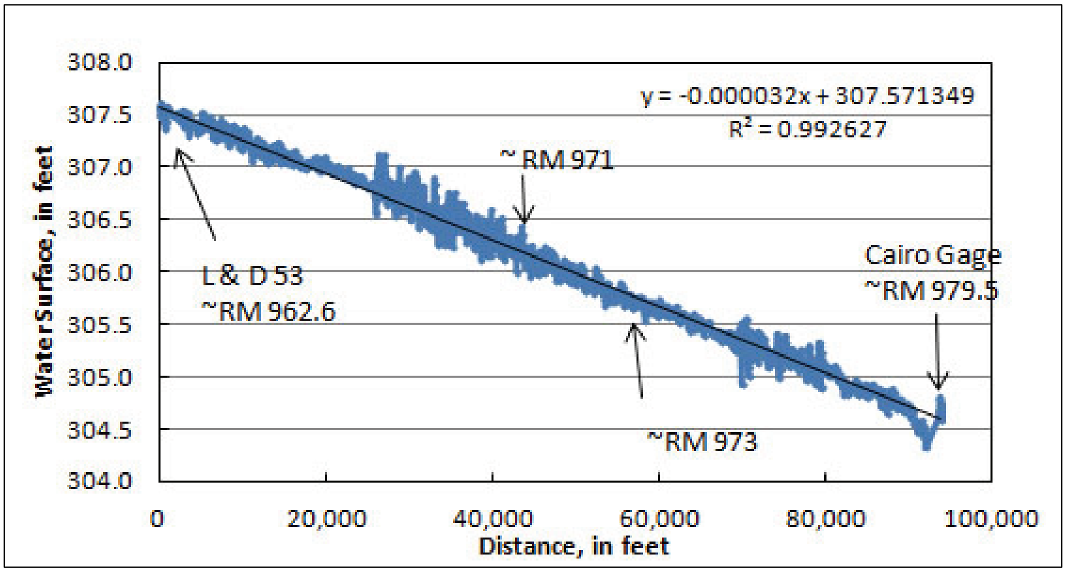
Figure 5. Material types 1 to 6 with assigned Manning Coefficient values.



To validate the model, comparisons were made to measured water surface slope and velocities. The profile on the Ohio River was collected on 28 March 2013 by the ERDC survey vessel, which made a run from Lock and Dam 53 to just south of Cairo, IL. The water surface profile data on the Ohio River were collected using an Applanix POS_MV system mounted on a 21 ft long, multibeam boat. The POS_MV system couples inertial measurements with dual frequency GPS measurements. GPS data were also collected at a fixed base station near the river. The position of this base station was verified using National Geodetic Survey (NGS) Online Positioning User Service (OPUS). The Applanix software package "POSPAC" was used to generate solution files by applying corrections from the base station data. The software uses data from the base stations and determines the best possible solution of the vessel position at a given time by forward processing, backward processing, and a combined processing. An ASCII

data file was output. The design of the boat hull causes the vessel to rise at speed. The boat speed and altitude were used to determine when to compensate for the plane effect. Figure 6 is a plot of the data. The slope of the linear regression line represents the slope of the water surface, which for these data is 0.000032.

Figure 6. Water surface slope determination using measured data from Lock and Dam 53 to USACE Cairo Gage OH111.



Additional data were acquired from the beginning and end points of the same reach from the river gages at Lock and Dam 53 and at Cairo, IL. Table 1 lists the river miles and water surface elevations (WSEL) measured at each location and shows the computed value of the slope using these data. It is essentially the same as the slope computed using the measured water surface from the boat survey. The value of 0.000032 can be used as a validation value for the model, with reasonable confidence.

Table 1. Water surface slope determination from river gages.

Gage	Lock and Dam 53	Cairo, IL
Datum	NGVD 1929	NGVD 1929
River Mile	962.6	979.5
Gage Reading (ft)	308.215	305.4
Δ Water Surface(ft)	2.815	
Δ River Reach Length (ft)	89232	
Water Surface Slope	0.0000315	

The steady-state base simulation produced an average water surface of 310.58 ft (94.688 m) at the upstream boundary and 308.48 ft (94.05 m) at the downstream boundary. This is a difference of 2.09 ft (0.638 m). The model channel length from the upstream to downstream boundary is approximately 67,896 ft (20,700 m). Thus, a computed slope for the model is 2.09 ft (0.638 m)/67896 ft (20,700 m), or approximately 0.0000308, or rounding up to 0.000031. This is very close to the measured value of 0.0000315. Using the observed slope (0.0000315), the expected upstream water surface elevation would be approximately 2.14 ft (0.65205 m) higher than the downstream boundary, or 310.62 ft (94.70 m). This indicates a model *error* of approximately .04 ft (0.012 m) or approximately 3/5 of 1 inch. This is certainly within measurement error, and thus the model can be considered validated with respect to the water surface slope.

The second model output that was used for model validation were the computed model velocities, which were compared to measured velocity values obtained during the March 2013 field data collection effort. The measured values were obtained at a cross section at RM 971 as shown in Figure 7.

The velocity values were obtained by an Acoustic Doppler Current Profiler (ADCP) unit and plotted on the AdH grid. Measured depth averaged values were compared to the model results at the nearest computational node location. These comparisons are shown in Figure 8.

The overall comparison is very good with the average difference being 6.3%, including the data points along the left descending bank. There is probably some bathymetric anomaly causing increased velocities at that specific location that is not picked up in the model. However, this is at the far extremity of the study's area of interest, and for that reason, the minor discrepancies between measured and computed velocities should not significantly affect model results in the navigation channel. Overall, the root mean square error for the two data sets is 0.09 fps (0.027 m/s).

Figure 7. Location of the velocity profile at River Mile 971 and shown in Figure 8.

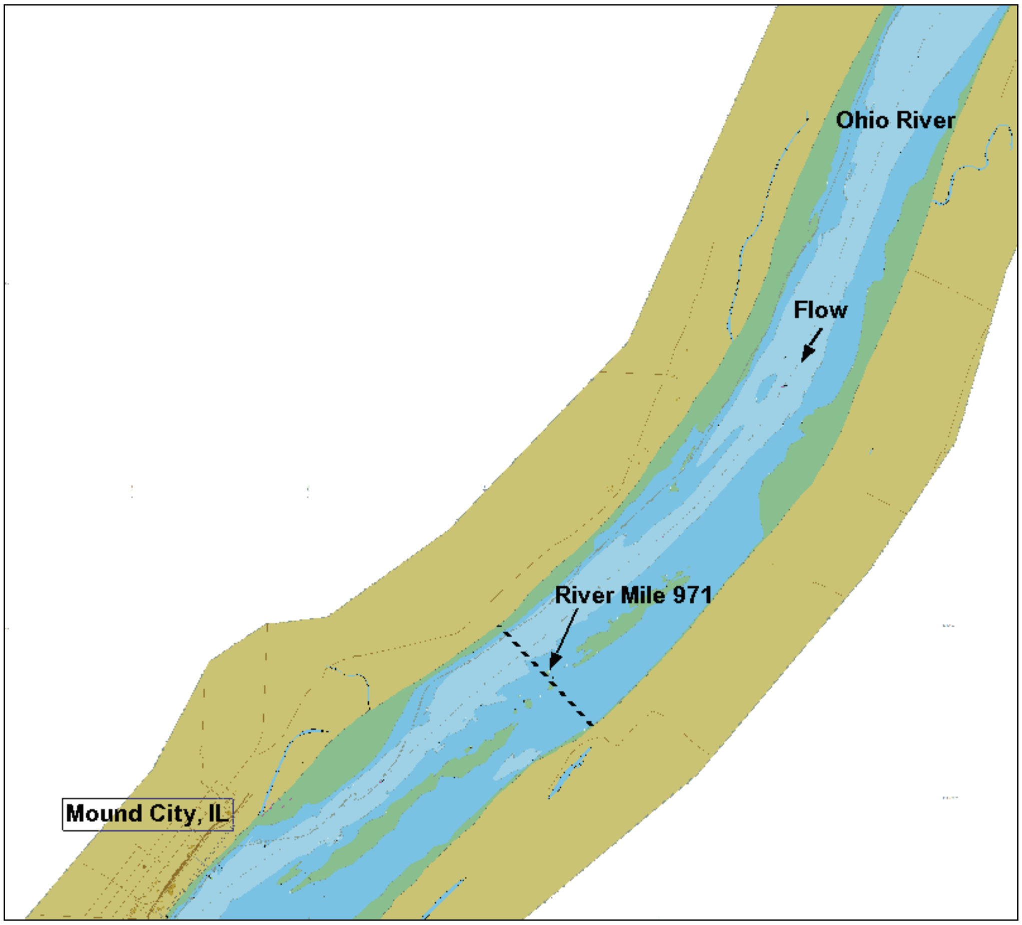
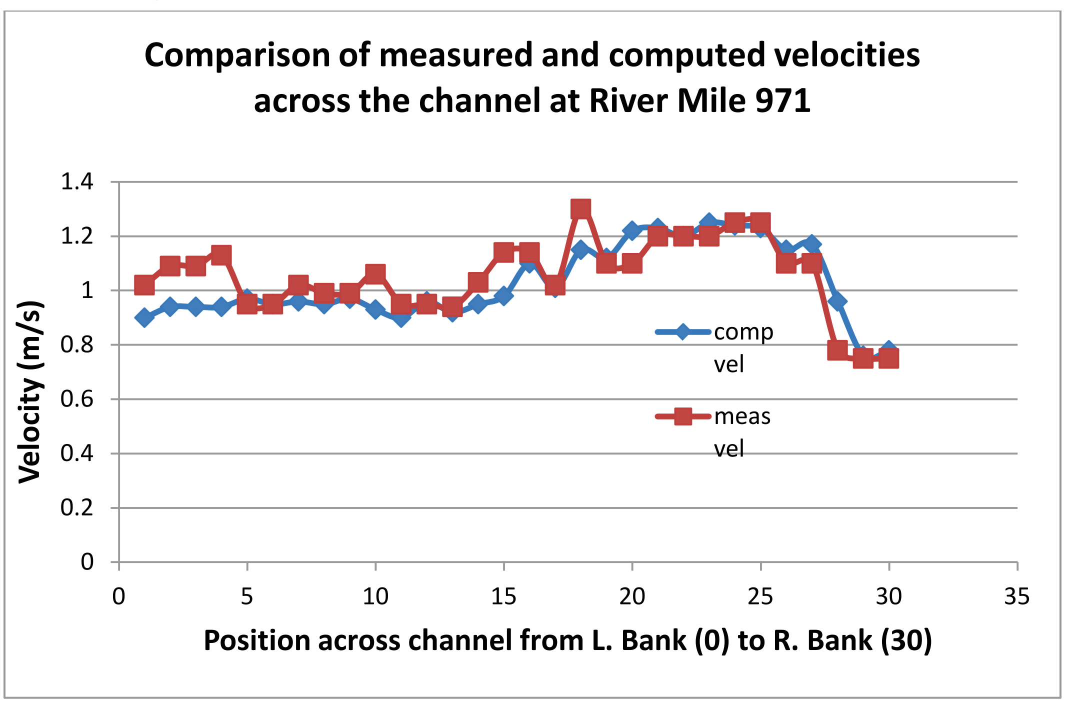


Figure 8. Comparison of computed and measured velocities at RM 971.



2.3 Model validation: Sediment

The model output considered for sediment model validation were suspended sediment (sand) concentrations and bed load in the vicinity of RM 971 to 973. Suspended sediment samples were collected at RM 971 as point samples collected with a P6 sampler at five different vertical positions. They were averaged to provide a measurement of total suspended material (TSM), which includes both wash load (fines with grain sizes less than 63 microns) and sands (grain sizes greater than 63 microns). Each sample was analyzed for weight fractions by grain size and tabulated. From these data, the percentage of sand in each sample could be multiplied by the TSM to arrive at the depth averaged measured sand concentration in milligrams per liter (mg/l). The depth averaged AdH model output results for suspended sand concentrations were collated for the corresponding locations at which the suspended samples were taken. The comparisons between measured and model values are listed in Table 2.

Table 2. Comparison of measured and computed (modeled) sand concentrations.

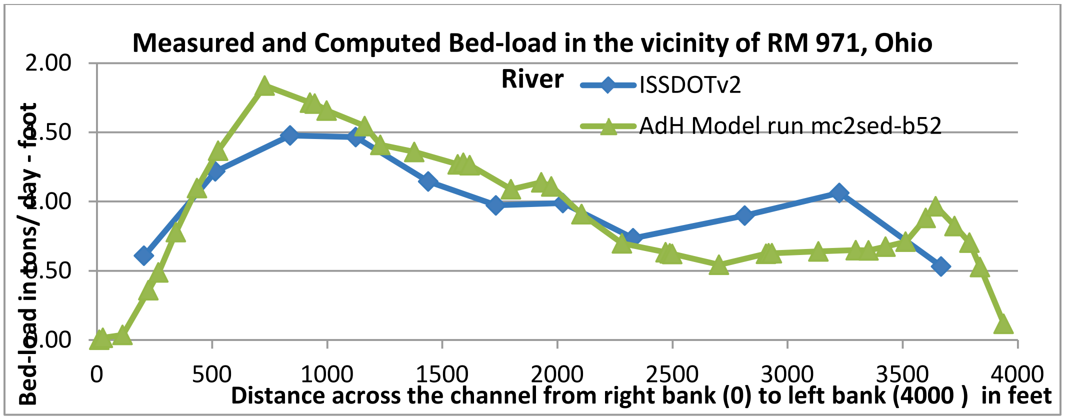
Station ID	Average Measured Sand Concentration, in mg/l	Modeled Sand Concentration, in mg/l	Percent Difference
MC971A	8.81	10.84	23
MC971B	10.98	12.85	17
MC971C	9.49	9.67	2
MC971D	8.02	9.21	15
MC971E	6.39	5.52	−14

The root mean square error for the two datasets is 1.4 mg/l. This is a measure of the difference, on average, between the measured and computed values, interpretable in terms of the measurement units. Simple percent differences were also computed. The maximum percent difference between the measured and modeled values is 23%. Either measure shows an acceptable range of difference between the measured and computed values for the suspended sediments.

The AdH model also computes bed-load values, that is, the portion of the bed-material load moving in the sand waves. During the field data collection effort in March 2013, sequential bathymetric swaths of the river bed were obtained. Using these data, the bed load was computed using the ISSDOTv2 bed-load technique of Abraham (2011). In addition to providing District personnel with a value of bed-load movement through the reach in

tons per day, the procedure also determines the lateral distribution of this load. Since the AdH model also computes a bed-load value at each node, the lateral variation in bed-load transport was compared between the field observations and the model. Figure 9 shows this comparison, with the left side of the figure being the right descending bank of the Ohio River.

Figure 9. Comparison of measured and computed bed load at RM 971.



The model-computed values of bed load compare very favorably with the ISSDOTv2 measured values. Based on the comparisons of the computed and measured total sand load (suspended load and bed load), the model was considered validated with regards to its sediment transport computations for the given flow conditions and sediment characteristics. The total bed load moving past RM 971 was measured to be 3,522 tons per day, and at RM 973 it was 2,529 tons per day. This corresponds to approximately a 28% reduction in bed-load transport from the upstream location to the downstream location. Figures 10 and 11 provide a spatial view of the sand waves for RM 971 and 973, respectively. They also show the bed-load transport by swath and for the entire cross section. A probable cause for seeing less bed load at RM 973 would be that more of the bed-material load has gone into suspension at that location (approximately 993 tons per day). This is consistent with a narrower navigation channel there due to the old structures in the river. The structures were placed there to constrict the flow, and these results seem to indicate that they are probably still functioning in that role. In Figures 10 and 11, IGR, IGM, and IGL indicate an Interpolated Gap in the bed-load measurement value located at Right, Middle and Left portion of the channel, respectively.

Figure 10. Measured bed-load transport in tons per day (tpd) at RM 971.

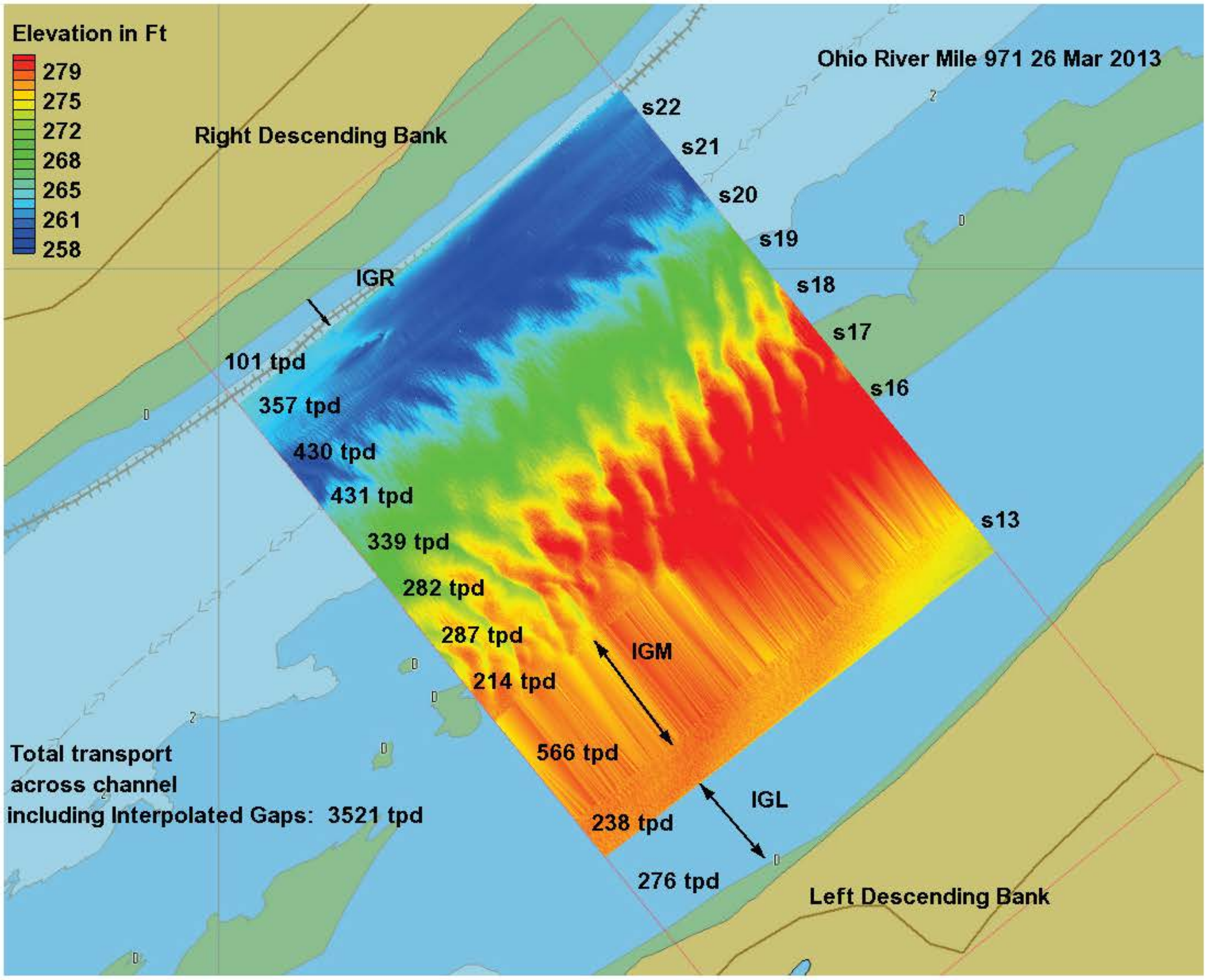
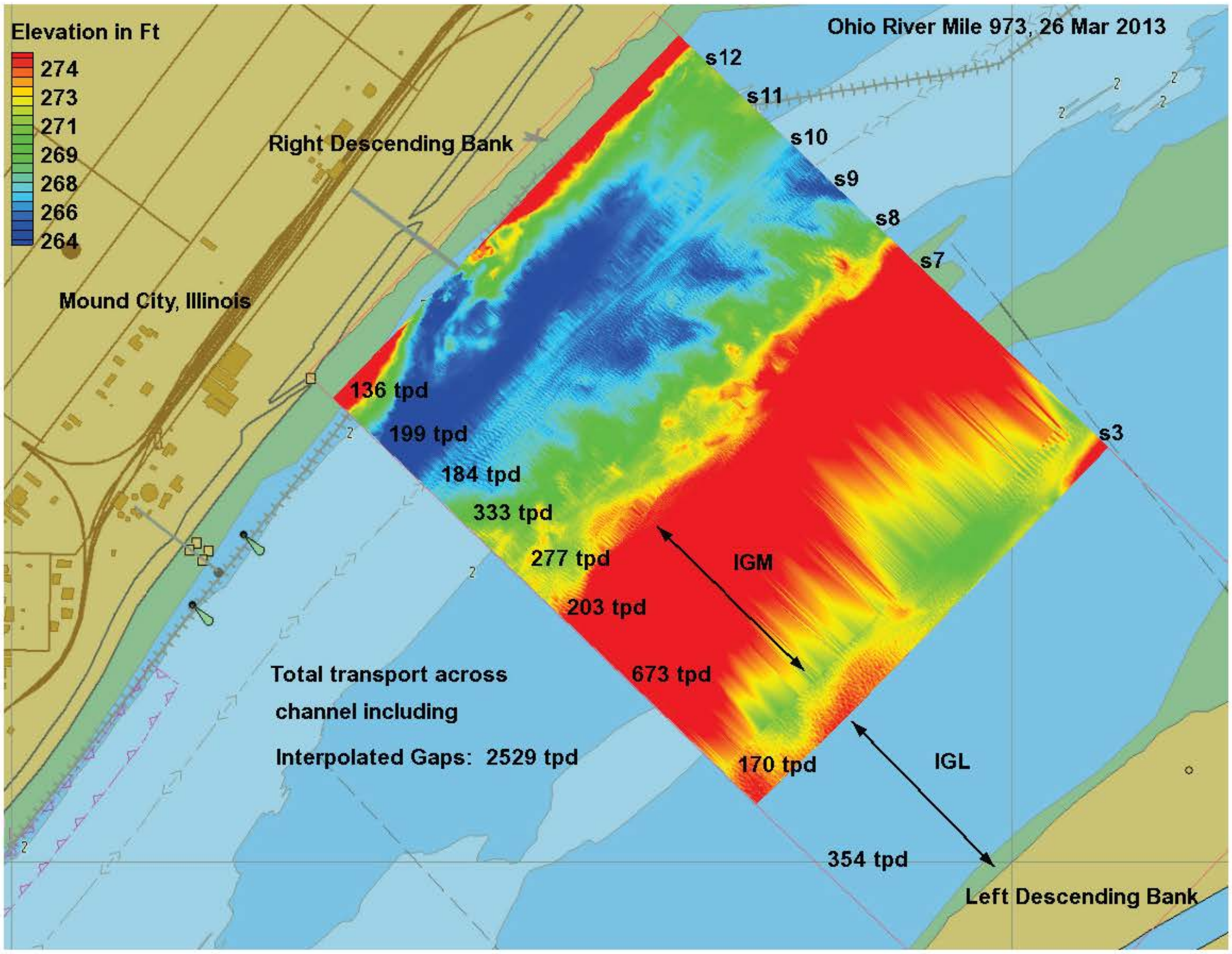


Figure 11. Measured bed-load transport in tons per day (tpd) at RM 973.



3 Model Simulations and Results

3.1 Steady-state simulations

To evaluate whether increasing the height of the two structures in the vicinity of RM 973 would reduce shoaling in the navigation channel, two simulations were run using a steady flow condition of 498,640 cfs (14,120 cms). The base condition used bathymetry and structure elevations as they presently exist and as previously shown in Figure 3. The plan condition raised the structures and any point of the sand bar or dune along the longitudinal axis of the dike that was below elevation 275.2 ft (83.9 m) to elevation 275.2 ft, as shown in Figure 4. The simulation was run for a period of 30 days at the flow mentioned above for both the base and plan condition. The greatest amount of deposition for the base condition was approximately 1 ft (0.3 m) near RM 970.5. At RM 973.7, the deposition was approximately 0.33 ft (0.1 m), shown in Figure 12. The legend in the figure shows negative values as scour and positive values as deposition.

The differences in deposition and scour between the base and plan conditions are shown in Figure 13. The legend in the figure shows negative values as scour and positive values as deposition. Differences are very minimal, with differences of approximately 0.16 ft (0.05 m) of deposition shown as light blue and scour with a maximum value of approximately 0.23 ft (0.07 m) shown as red and yellow.

3.2 Unsteady simulations

After running the steady-state simulation and seeing that raising the structures 1 ft (0.33 m) had a very small effect on reducing shoaling in the navigation channel, a discussion was initiated with the District. It was decided that a steady-state or single, continuous flow did not really represent what happens when significant deposition occurs in natural river conditions. In those conditions, there is usually some rising or falling of stage and flow. Therefore, an unsteady simulation was pursued. The hydrograph selected had a moderate base flow of approximately 75,000 cfs (2,124 cms). The hydrograph contained one distinct flood wave starting on 25 Jul 2012 at 56,000 cfs (1,586 cms), peaking on 30 July at 152,000 cfs (4,304 cms) and then receding to 56,000 cfs on 3 August 2012. The rising and receding limbs of this hydrograph covered 9 days. The entire hydro-

graph covered 48 days from 14 July to 31 August 2012 and contained several smaller rising and receding limbs as well. The hydrograph is shown in Figure 14.

Figure 12. Bed change, in meters, for the base condition after a 30-day, steady-state simulation.

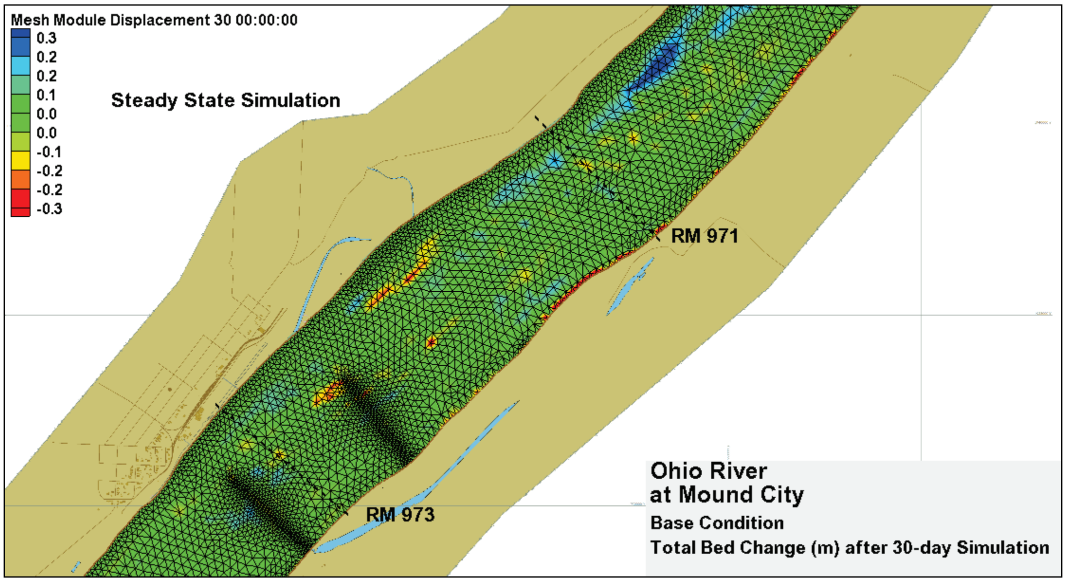


Figure 13. Bed change, in meters, between the base and plan conditions for the steady-state run.

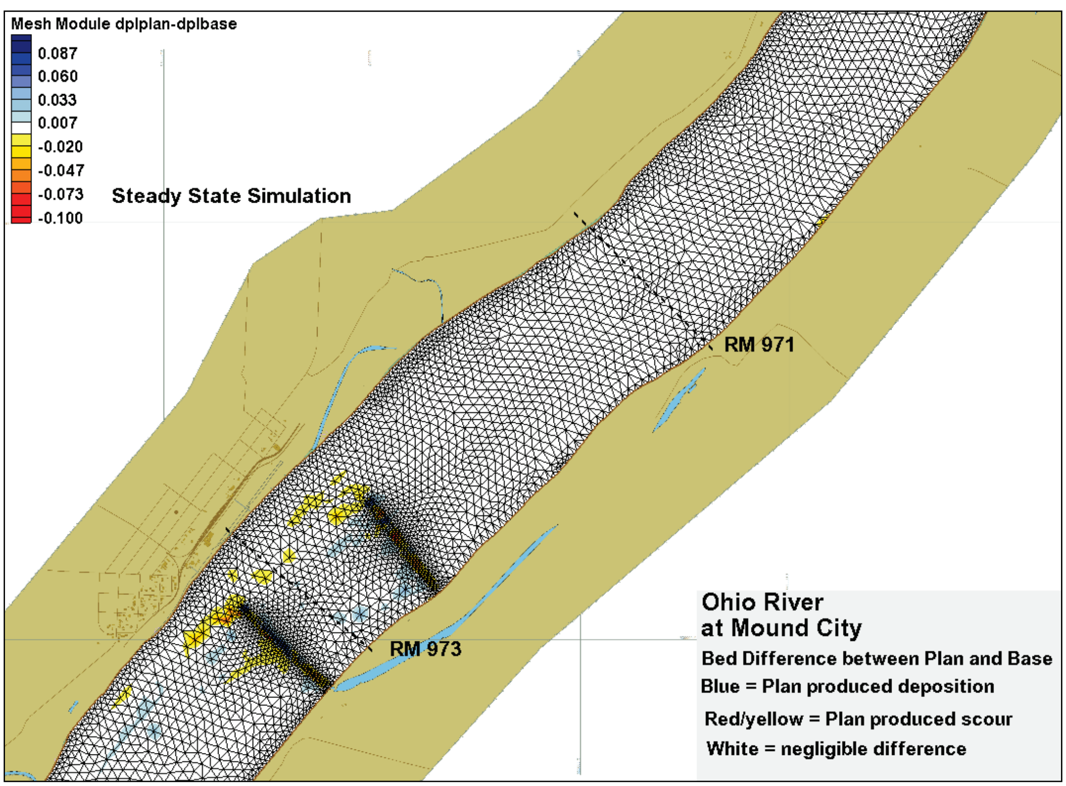
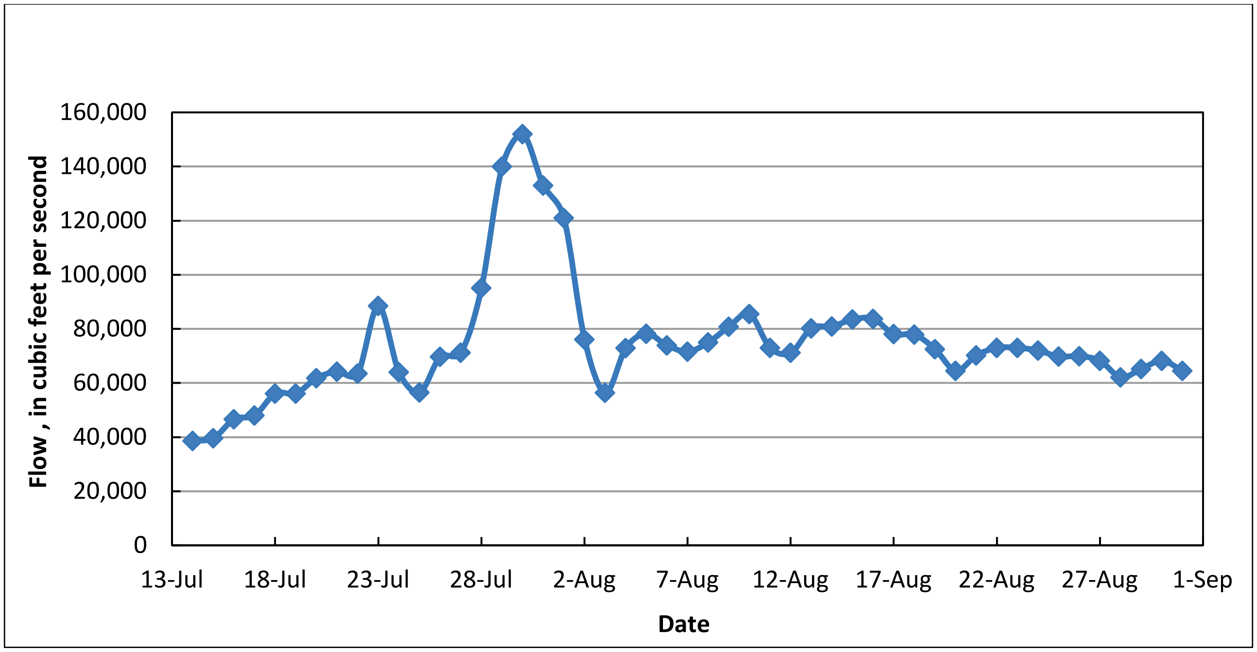
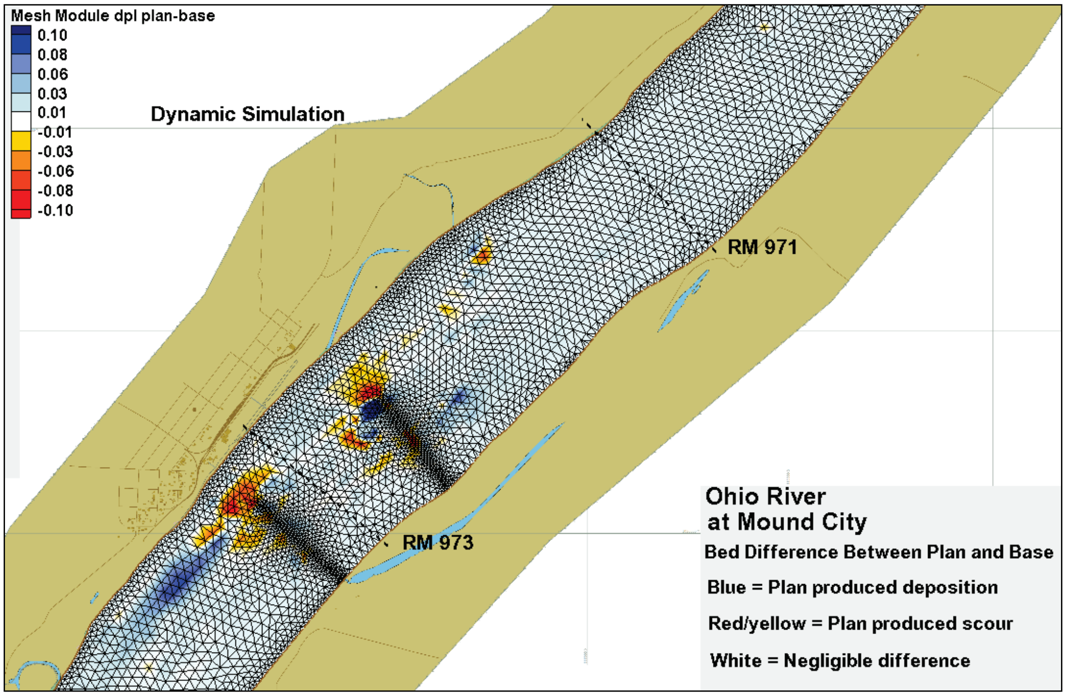


Figure 14. Ohio River in the vicinity of Mound City, IL, hydrograph used in the unsteady simulation.



A 10-day model spin up was added on the front end of the hydrograph with a constant flow of 38,599 cfs (1,093 cms). The complete simulation hydrograph was therefore 58 days with both the base and plan conditions being run with the same hydrograph. The only differences in the runs were the structure elevations that were raised by 1 ft (0.33 m) and the structure roughness that was increased due to newly placed stone, in the plan condition. Therefore, as in the steady-state runs, any difference in the bed elevations is attributable to raising the structures. The results of these simulations are shown in Figure 15. The legend in the figure shows negative values as scour and positive values as deposition. There are some differences between the base and plan conditions in the main channel, but they are limited in spatial extent and depth. The greatest differences are at the upstream structure where the plan produced up to 0.5 ft (0.15 m) more deposition than the base condition. This occurred at the tip of the structure; however, nearby more deposition occurred in the plan than in the base on the downstream side of the same structure. In any case, these represent local reactions to the changes between the base and plan conditions. A similar effect is noted at the tip of the downstream structure. However, as noted by the orange colors in the main channel (Figure 15), slight reductions of deposition are attained for short distances upstream, between, and downstream of the structures. Finally, the net sediment being moved through the channel is depositing downstream of the second structure, shown as a blue band in the channel.

Figure 15. Bed change, in meters, between the base and plan conditions for the unsteady simulation.



3.3 Conclusions

The steady-state simulations show very little change in the deposition patterns between the base and plan conditions (0.16 ft or 0.05 m). This indicates that raising the structures 1 ft has very little impact in reducing shoaling in the navigation channel. The largest change in bed elevation in the navigation channel was relatively small (approximately 1 ft or 0.33 m). One factor that does influence deposition tendencies in a river other than flow and river geometry is the effect of a hydrograph. In most cases, a river entrains more sediment on the rising limb of the hydrograph and tends to be more depositional on the falling limb of the hydrograph. Knowing this, an unsteady simulation consisting of continuously changing flows with rising and falling portions was considered. Actual Ohio River flow and stage records were examined, and the hydrograph shown in Figure 14 simulated. In this way, the added effects of sediment entrainment and deposition inherent in a hydrograph would be accounted for in the model simulation. The hydrograph simulation resulted in approximately 0.33 ft (0.1 m) more deposition than the steady-state simulation. Even though the unsteady simulation was for a longer duration, the maximum flow of 152,000 cfs (4,304 cms) was approximately 1/3 of the flow for the steady state simulation, and that was for a very short period of time. Both

simulations showed that raising the structures was not helpful in reducing shoaling in the desired area of the navigation channel.

Future studies at this location should take this into account and be designed around measured historical deposition events for which the flow and stage conditions of both the Ohio and Mississippi Rivers are known. Once the model is validated to those known conditions, it can be used for various stage and flow conditions to test the sediment transport sensitivity of the two-river system to additional system alterations. Worst case sedimentation scenarios could be identified, and then mitigation efforts planned. Such mitigation efforts could consist of further structural modifications to the existing structures and/or varying the discharge releases from the upstream dams. The present model could be extended upstream to Olmsted Lock and Dam and downstream to include a portion of the Mississippi River, if desired.

References

Abraham D., R. Kuhnle, and A. J. Odgaard. 2011. Validation of bed-load transport measurements with time-sequenced bathymetric data. *ASCE Journal of Hydraulic Engineering* 137(7):723–728.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
A numerical sedimentation study was conducted on the Ohio River in the vicinity of Mound City, Illinois. The purpose of the study was to evaluate shoaling tendencies between river miles 971 and 973.2. The model was used to determine if raising the elevations of two existing transverse would reduce shoaling at that location. First the model was run in a base (as is) condition, and calibrated to both hydraulic and sediment field measurements. Then the crest elevations of the existing dikes were raised by one foot. Plan condition simulations were then made for a steady-state bankfull flow of 498,650 cfs (14,120.4 cms) , and an unsteady simulation consisting of a 48 day hydrograph from 14 Jul – 31 Aug 2012, which had a peak flow of 152,000 cfs (4,304.2 cms) . The steady state simulation showed a difference of 0.16 ft (0.05 m), between the base and plan conditions, and for the unsteady simulation a difference of 0.33 ft (0.1 m). These results indicate that raising the structures 1 foot has little effect on shoaling in the navigation channel. In the future this model can be modified to test additional structural and/or operational changes that might reduce shoaling.

15. SUBJECT TERMS		
River	Shoaling	Bed load
Sedimentation	Numerical model	Multibeam
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